WECN Structural Embedding/Removal

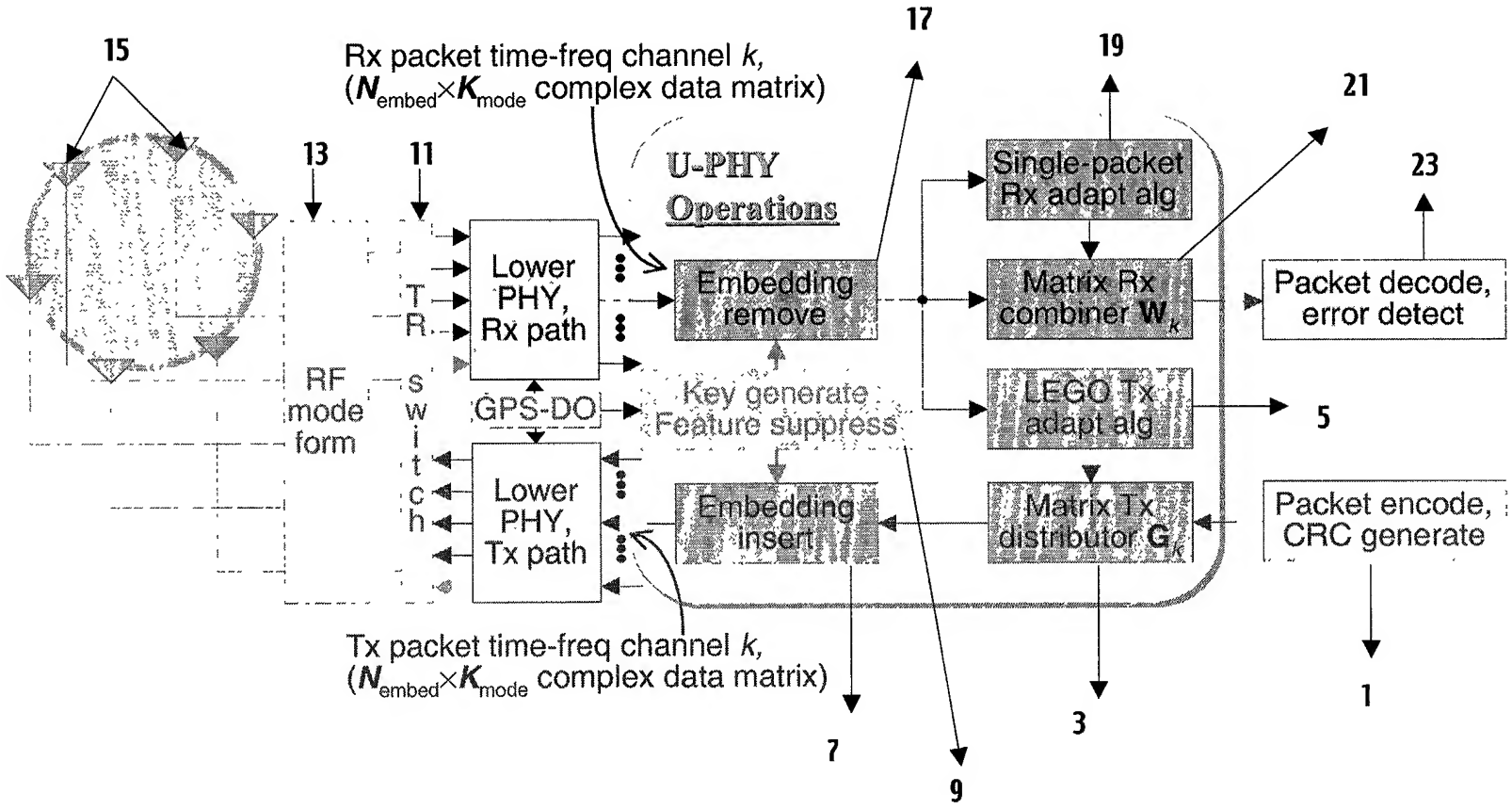


Figure 1

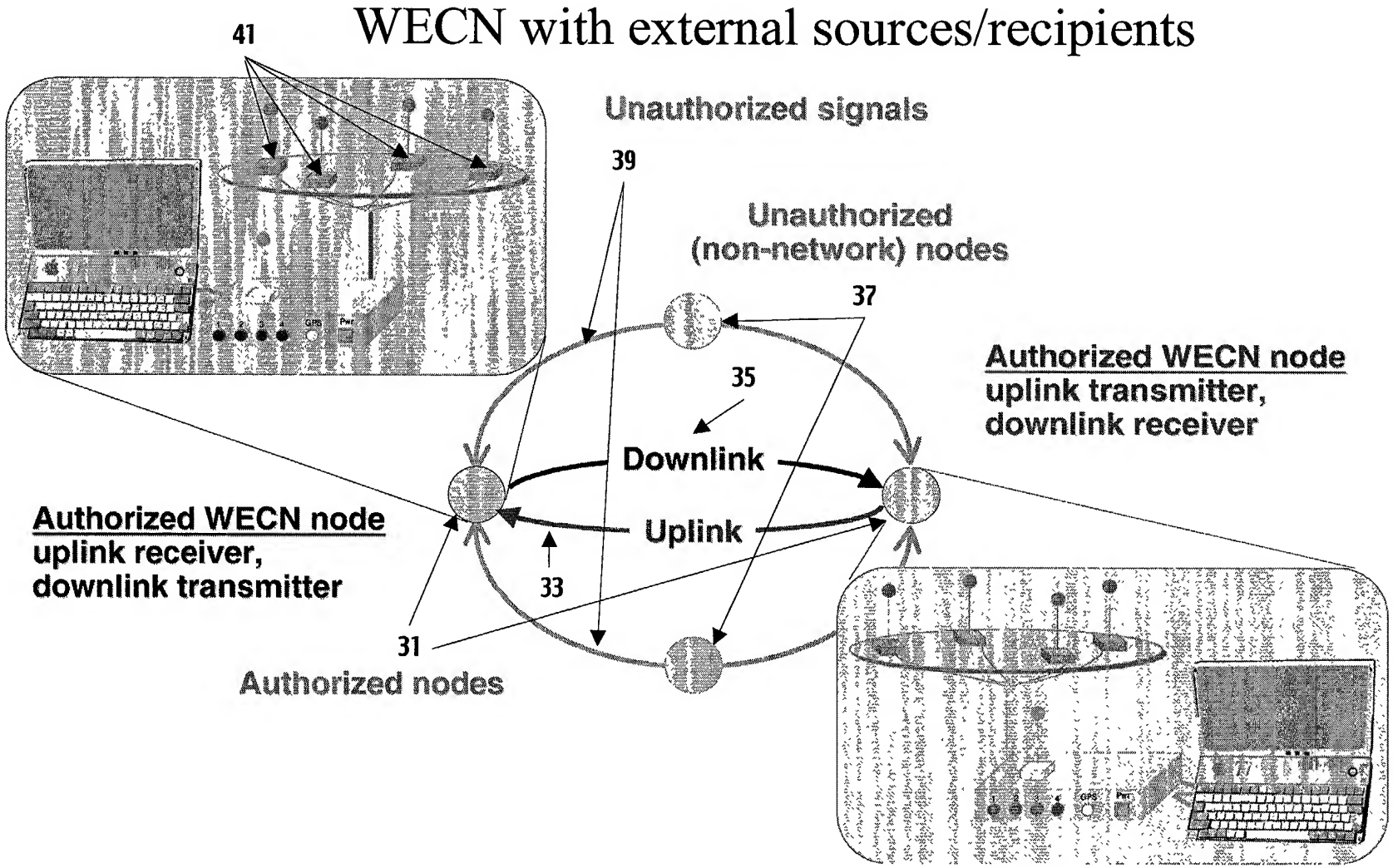

WECN with external sources/recipients
41
Unauthorized signals
39
Unauthorized
(non-network) nodes
37
35
Downlink
Uplink
33
Authorized WECN node
uplink transmitter,
downlink receiver
Authorized WECN node
uplink receiver,
downlink transmitter
31
Authorized nodes

Figure 2

Time-Slot Embedding

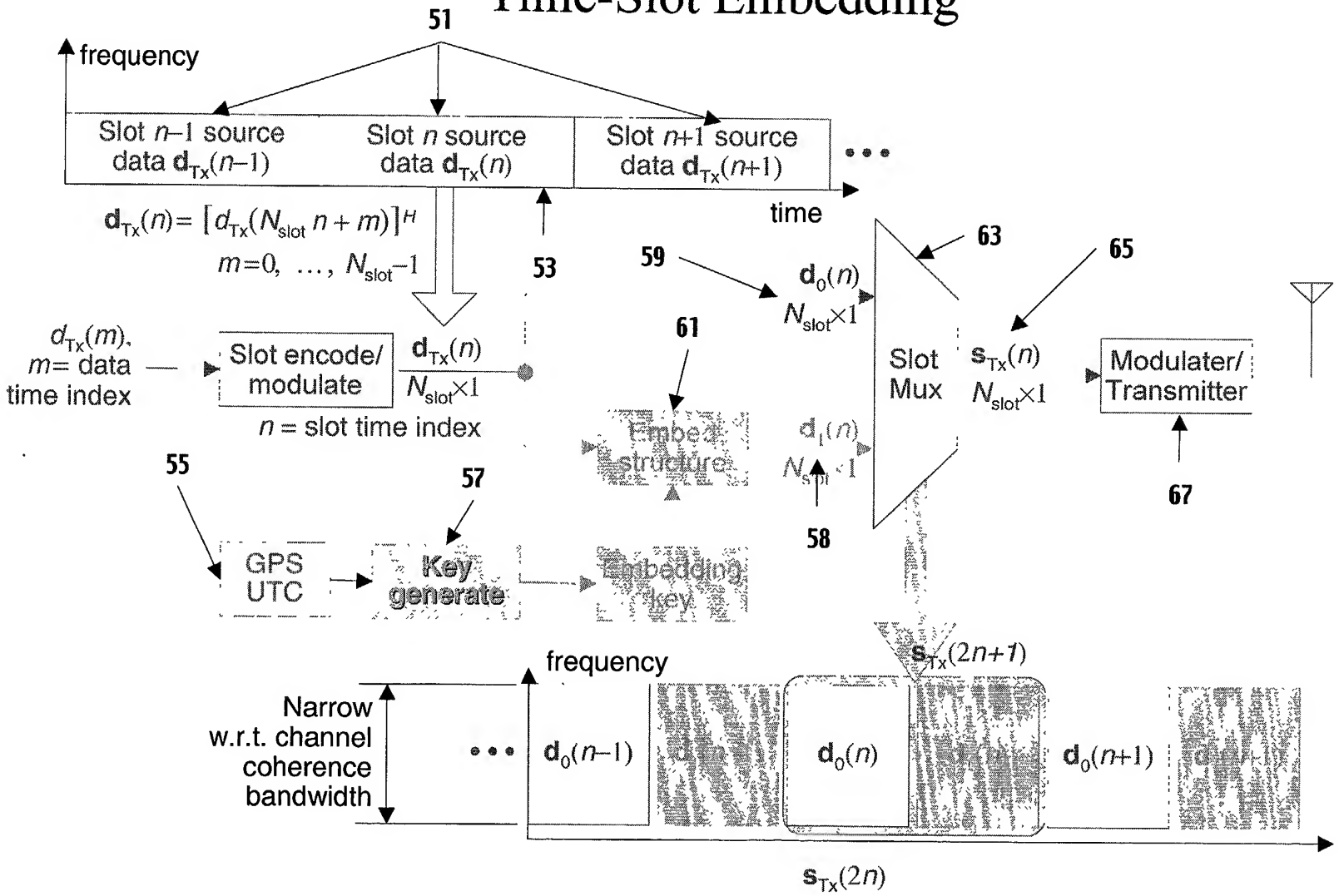


Figure 3

Time-Slot Reception/Removal

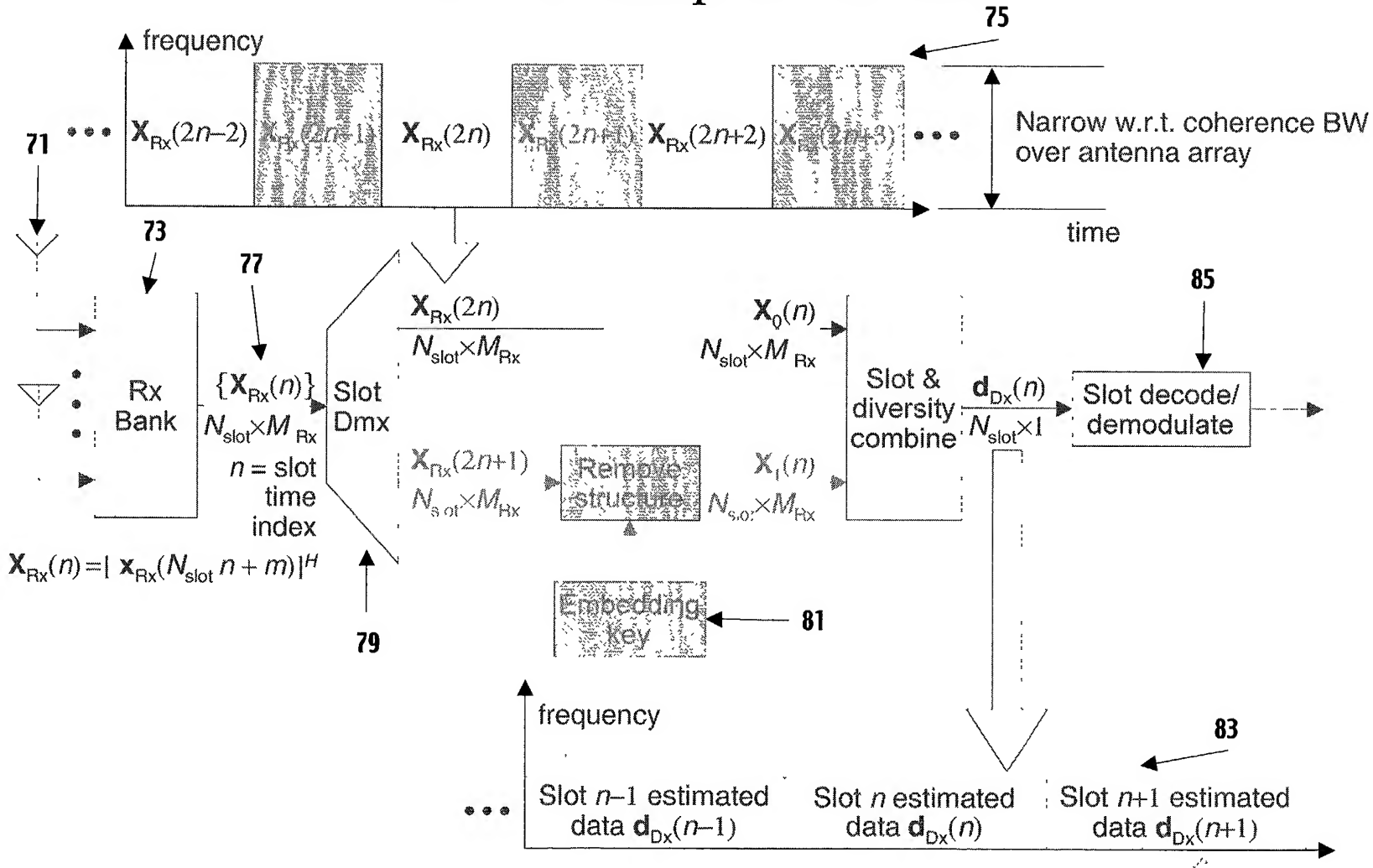


Figure 4

Delay-Invariant Embedding

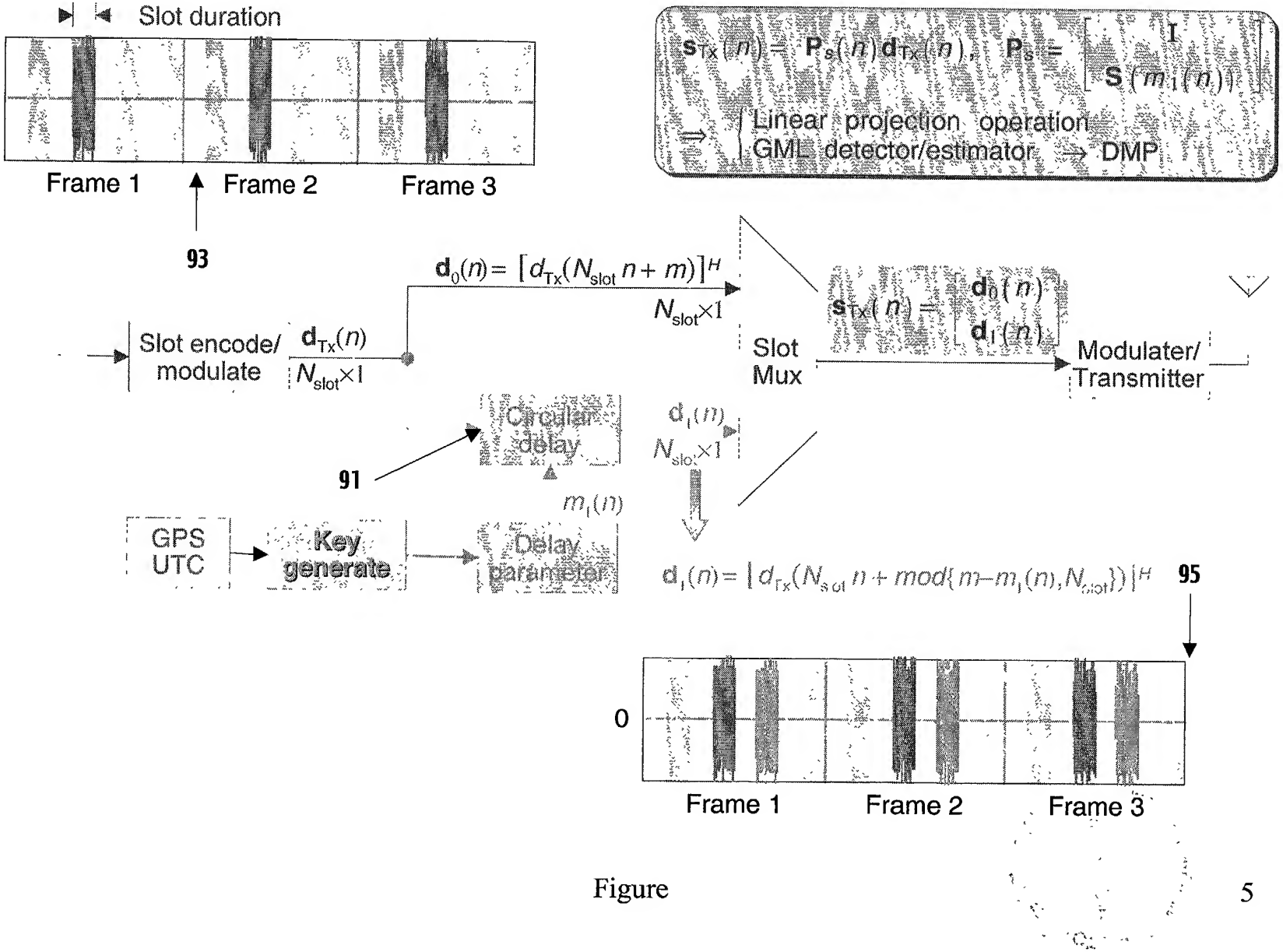
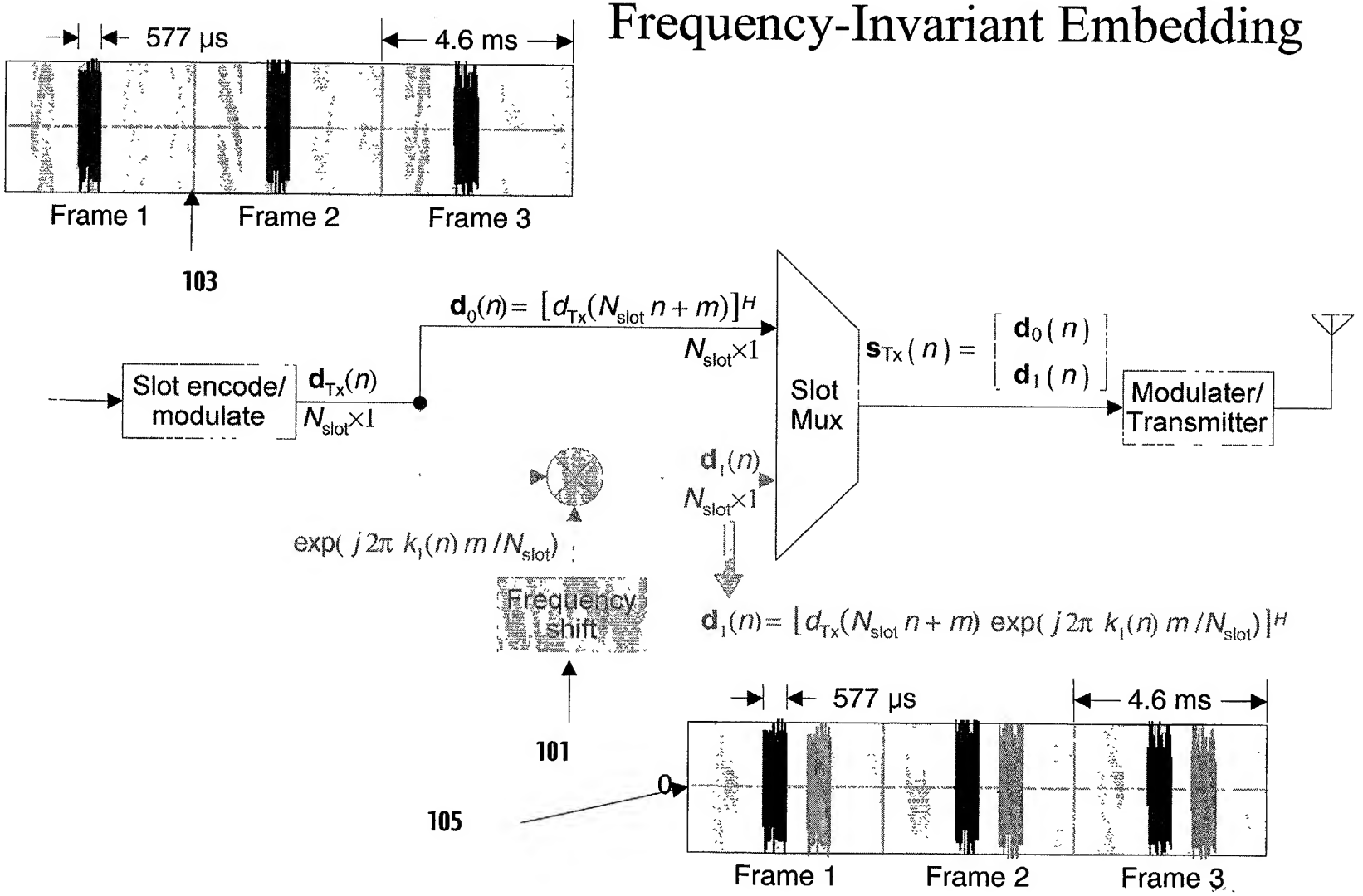


Figure 5

Frequency-Invariant Embedding



Figure

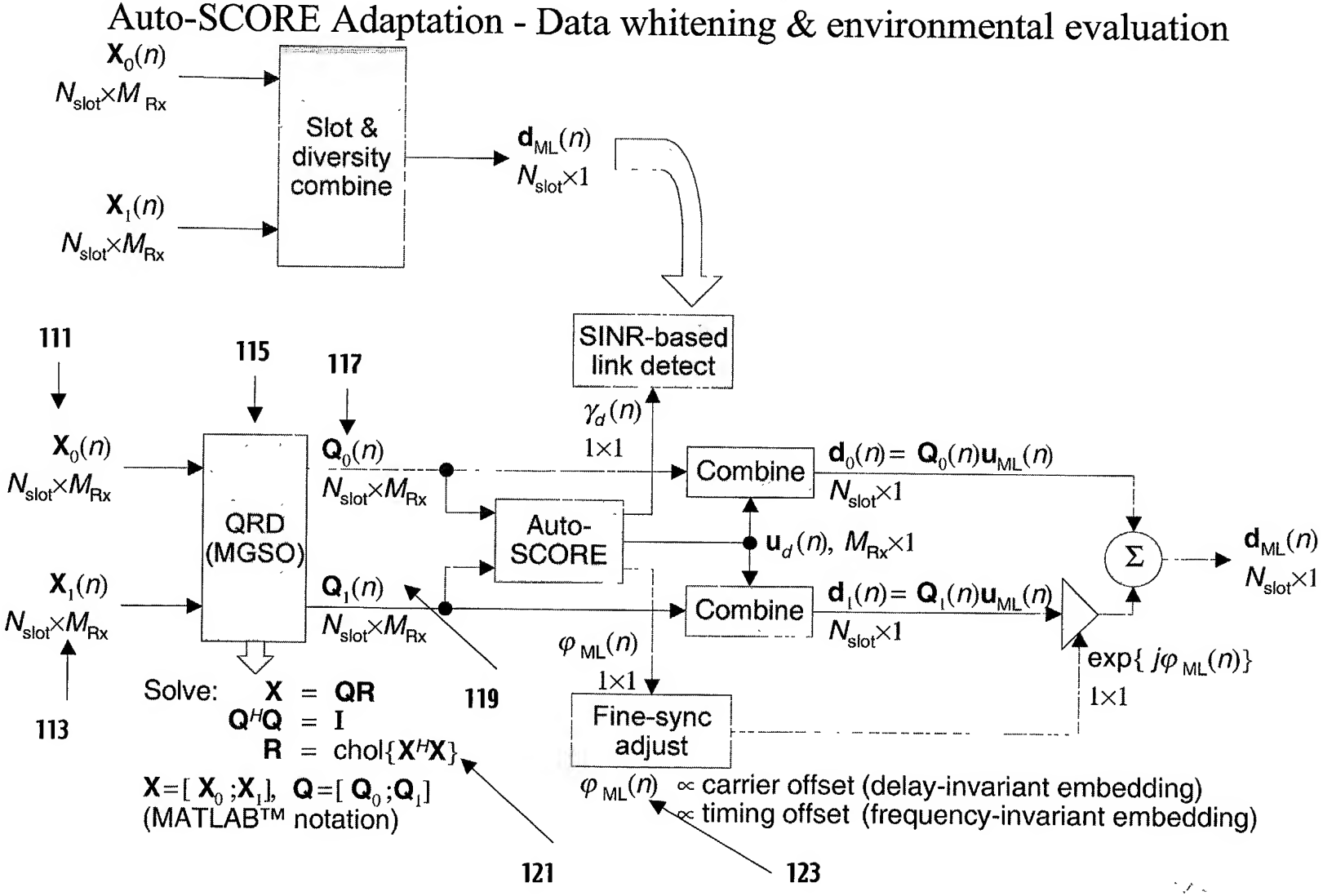
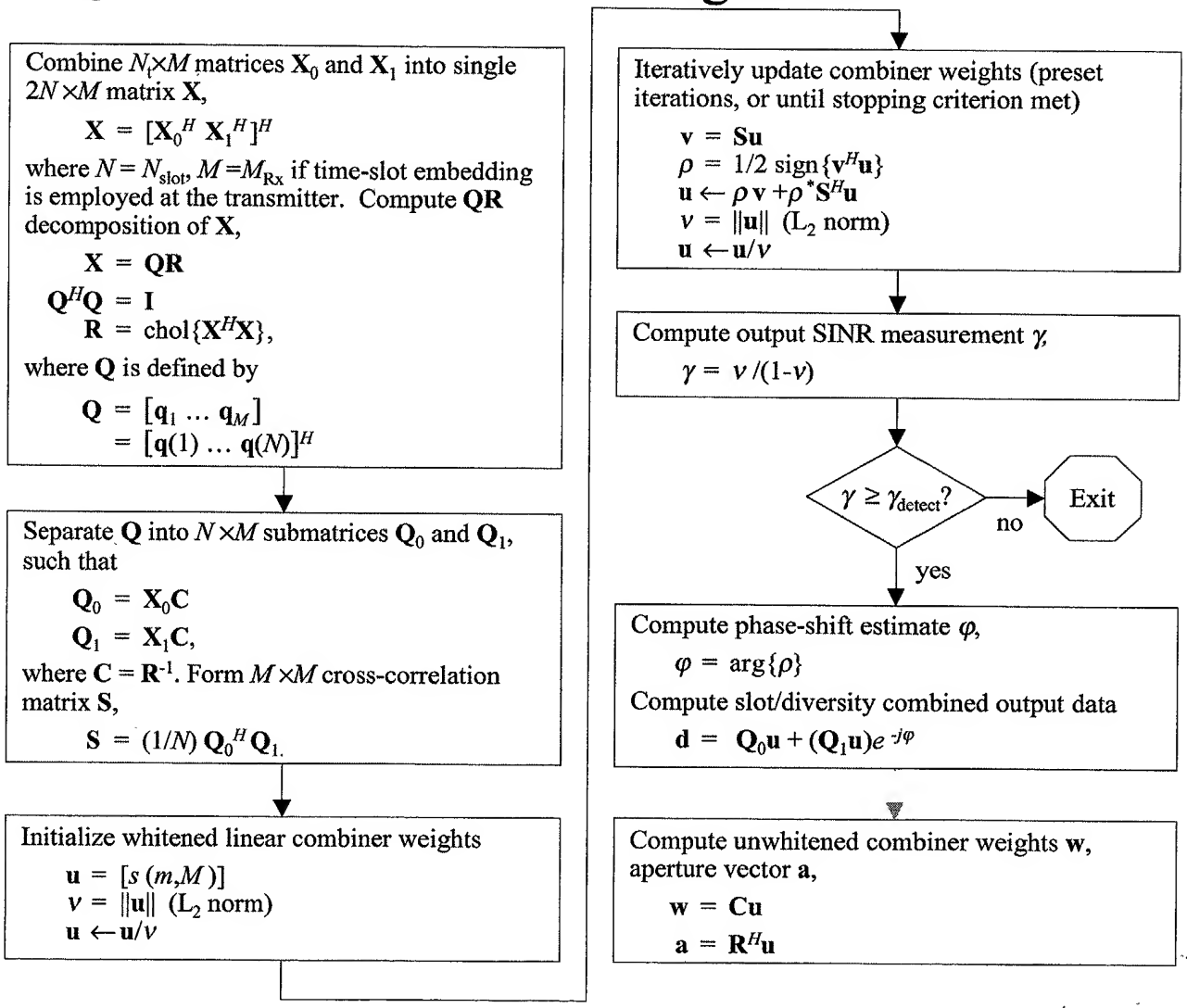

Auto-SCORE Adaptation - Data whitening & environmental evaluation
$\mathbf{X}_0(n)$
$N_{slot}\times M_{Rx}$
$\mathbf{X}_1(n)$
$N_{slot}\times M_{Rx}$
Slot & diversity combine
$\mathbf{d}_{ML}(n)$
$N_{slot}\times 1$
SINR-based link detect
$\gamma_d(n)$
1×1
111
115
117
$\mathbf{X}_0(n)$
$N_{slot}\times M_{Rx}$
QRD (MGSO)
$\mathbf{Q}_0(n)$
$N_{slot}\times M_{Rx}$
Auto-SCORE
Combine
$\mathbf{d}_0(n)=\mathbf{Q}_0(n)\mathbf{u}_{ML}(n)$
$N_{slot}\times 1$
$\mathbf{u}_d(n)$, $M_{Rx}\times 1$
$\mathbf{X}_1(n)$
$N_{slot}\times M_{Rx}$
$\mathbf{Q}_1(n)$
$N_{slot}\times M_{Rx}$
Combine
$\mathbf{d}_1(n)=\mathbf{Q}_1(n)\mathbf{u}_{ML}(n)$
$N_{slot}\times 1$
Σ
$\mathbf{d}_{ML}(n)$
$N_{slot}\times 1$
113
119
$\varphi_{ML}(n)$
1×1
exp{ $j\varphi_{ML}(n)$}
1×1
Solve: $\mathbf{X} = \mathbf{QR}$
$\mathbf{Q}^H\mathbf{Q} = \mathbf{I}$
$\mathbf{R} = \text{chol}\{\mathbf{X}^H\mathbf{X}\}$
Fine-sync adjust
$\mathbf{X}=[\mathbf{X}_0;\mathbf{X}_1]$, $\mathbf{Q}=[\mathbf{Q}_0;\mathbf{Q}_1]$
(MATLAB™ notation)
$\varphi_{ML}(n)$ ∝ carrier offset (delay-invariant embedding)
∝ timing offset (frequency-invariant embedding)
121
123

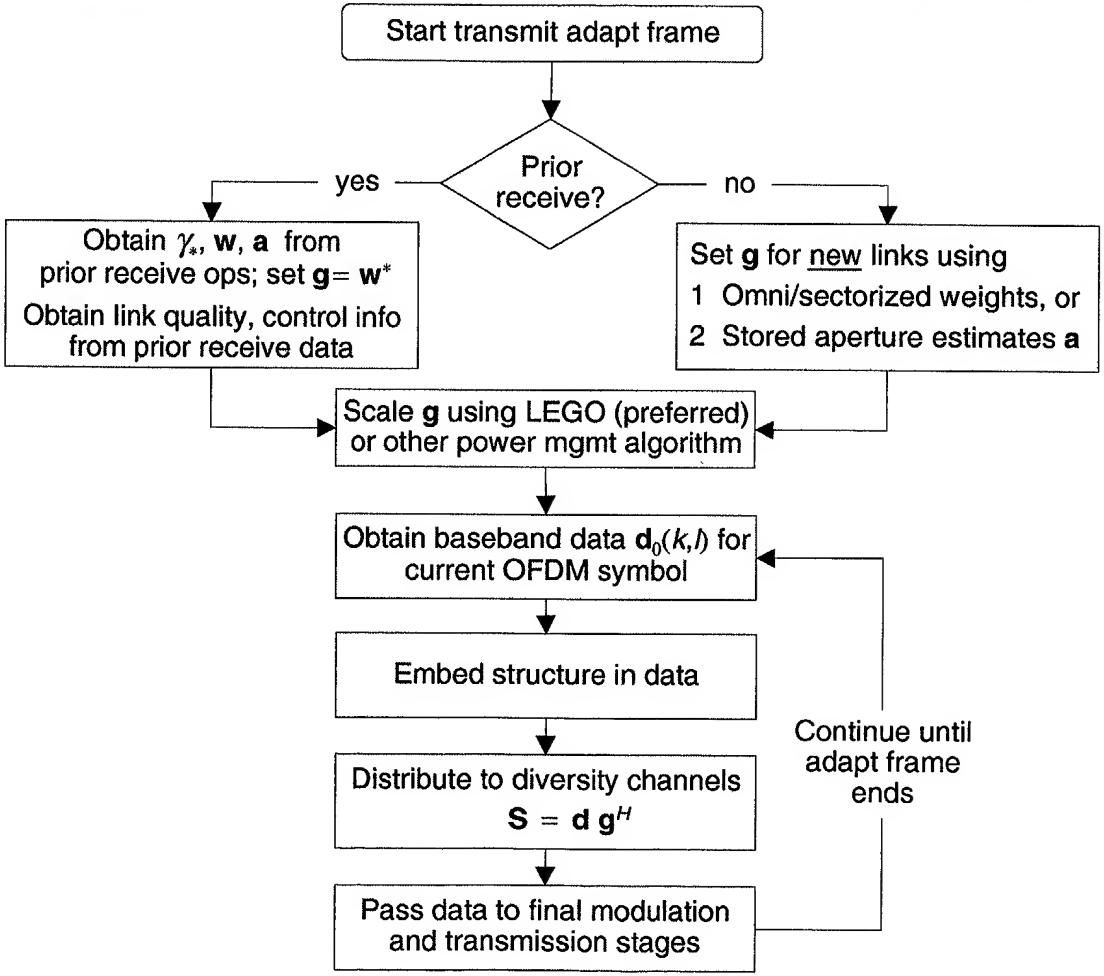
Figure 7

Single-Link Auto-SCORE Algorithm - Software



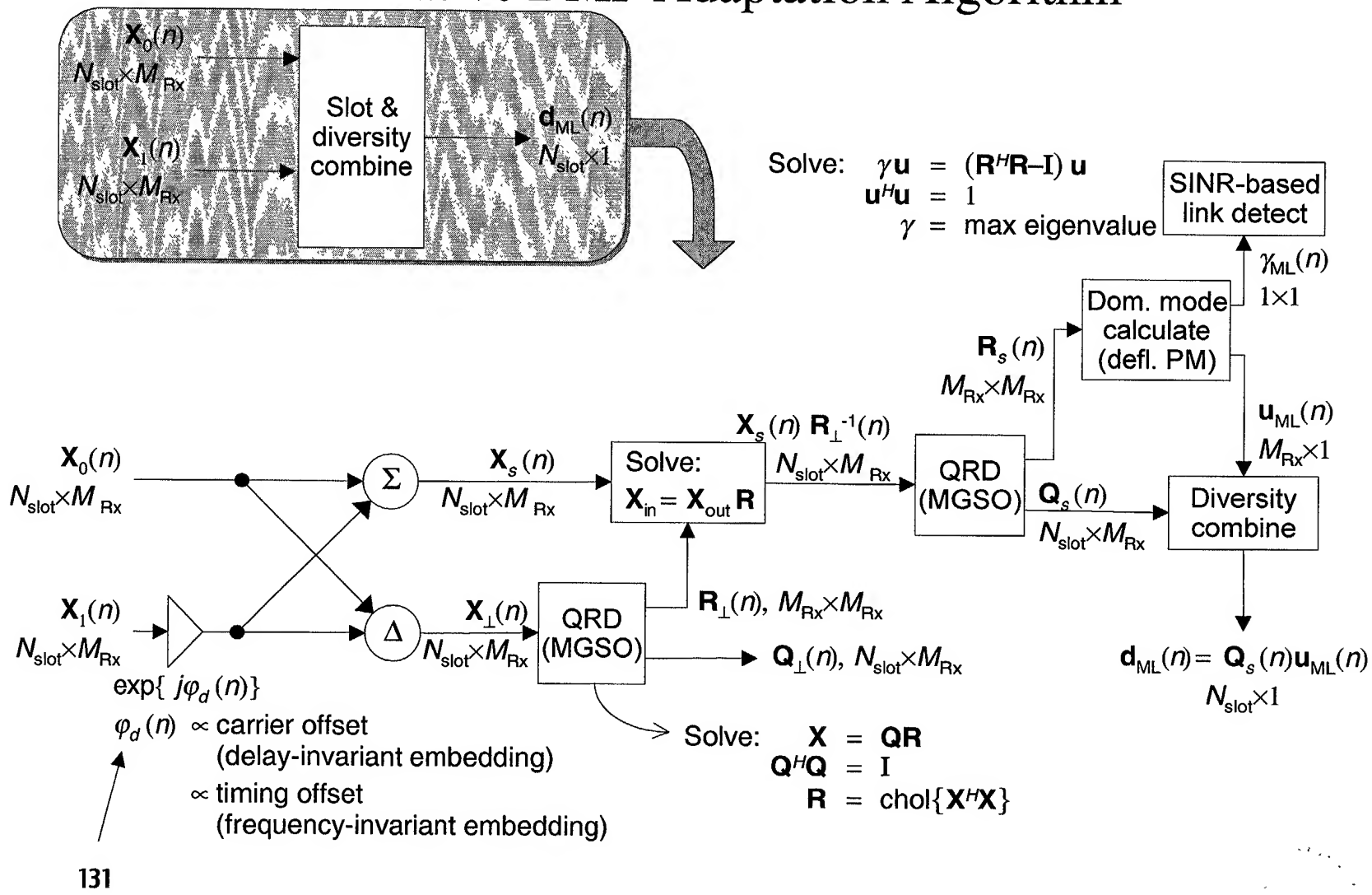
Figure

Single-Link Transmitter Flow Diagram



Figure

Alternative DMP Adaptation Algorithm



Figure

alternative converging embedded-signal-differentiation algorithms

Dominant-Mode Prediction

Solve:
$$\gamma \mathbf{u} = (\mathbf{R}^H\mathbf{R} - \mathrm{I})\,\mathbf{u}$$
$$\|\mathbf{u}\| = 1 \quad (\mathrm{L}_2 \text{ norm})$$
$$\gamma = \text{max eigenvalue}$$

Auto-SCORE

Solve:
$$\nu(\varphi)\,\mathbf{u} = \mathbf{S}(\varphi)\,\mathbf{u}$$
$$\mathbf{S}(\varphi) = 1/2(\mathbf{S}e^{j\varphi} + \mathbf{S}^H e^{-j\varphi})$$
$$\|\mathbf{u}\| = 1 \quad (\mathrm{L}_2 \text{ norm})$$
$$\nu(\varphi) = \text{max eigenvalue}$$
$$\varphi = \arg\max_{\varphi} \nu(\varphi)$$

Optimization Algorithm

Initialize:
$$\mathbf{u} = r(M,M)\,[\,r^*(M,1) - 1\,]$$
$$\gamma = \|\mathbf{u}\| \quad (\mathrm{L}_2 \text{ norm})$$
$$\mathbf{u} \leftarrow \mathbf{u}/\gamma$$

Iterate:
$$\mathbf{v} = \mathbf{R}\,\mathbf{u}$$
$$\mathbf{u} \leftarrow \mathbf{R}^H\mathbf{v} - \mathbf{u}$$
$$\gamma = \|\mathbf{u}\| \quad (\mathrm{L}_2 \text{ norm})$$
$$\mathbf{u} \leftarrow \mathbf{u}/\gamma$$

Optimization Algorithm

Initialize:
$$\mathbf{u} = [s(m,M)]$$
$$\nu = \|\mathbf{u}\| \quad (\mathrm{L}_2 \text{ norm})$$
$$\mathbf{u} \leftarrow \mathbf{u}/\nu$$

Iterate:
$$\mathbf{v} = \mathbf{S}\mathbf{u}$$
$$\rho = 1/2\ \text{sign}\{\mathbf{v}^H\mathbf{u}\}$$
$$\mathbf{u} \leftarrow \rho\,\mathbf{v} + \rho^*\mathbf{S}^H\mathbf{u}$$
$$\nu = \|\mathbf{u}\| \quad (\mathrm{L}_2 \text{ norm})$$
$$\mathbf{u} \leftarrow \mathbf{u}/\nu$$

Finalize:
$$\varphi = \arg\{\rho\}$$
$$\gamma = \nu/(1-\nu)$$

Figure

Embedded Invariance Flowchart (Nodal View)

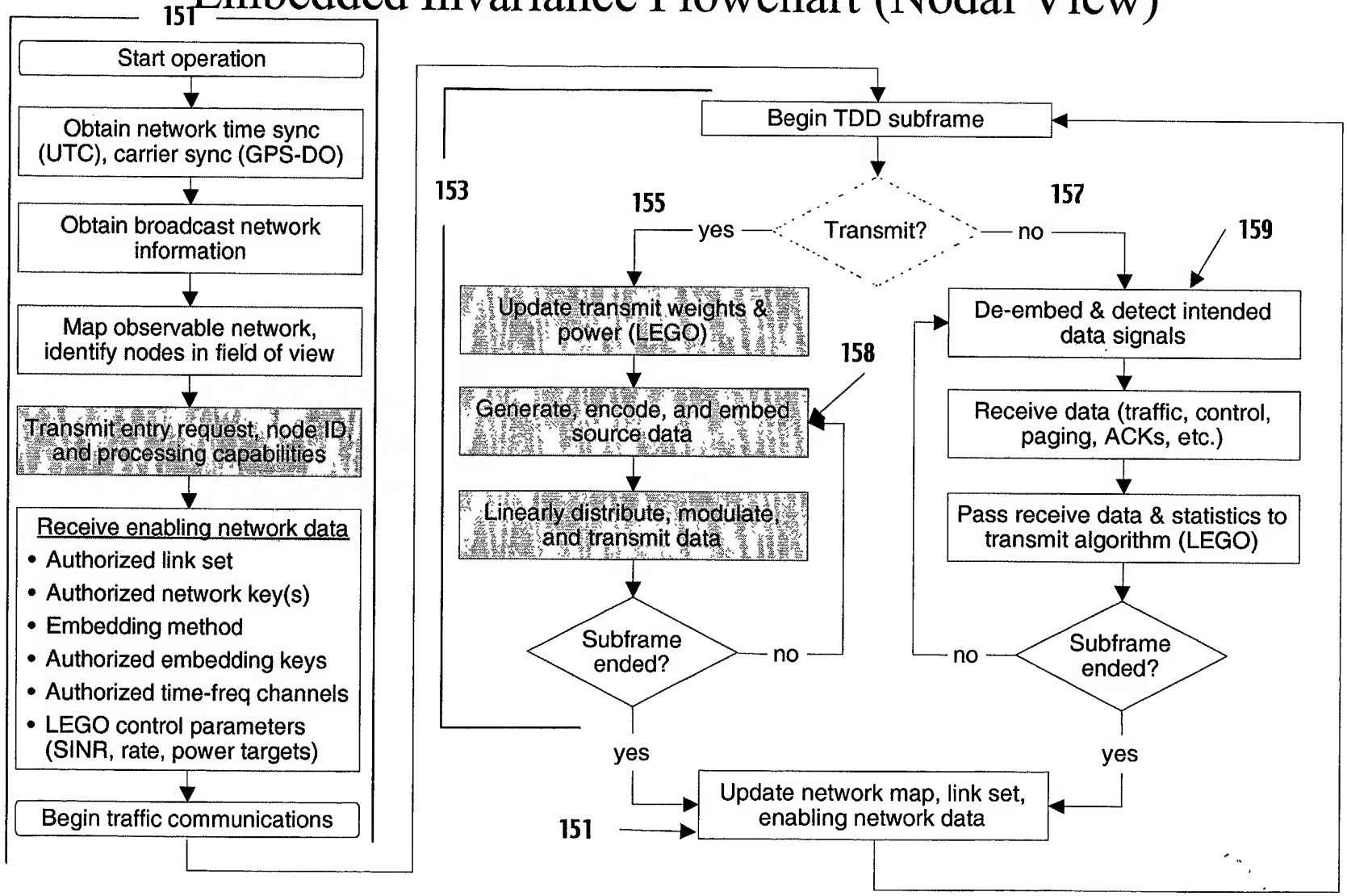
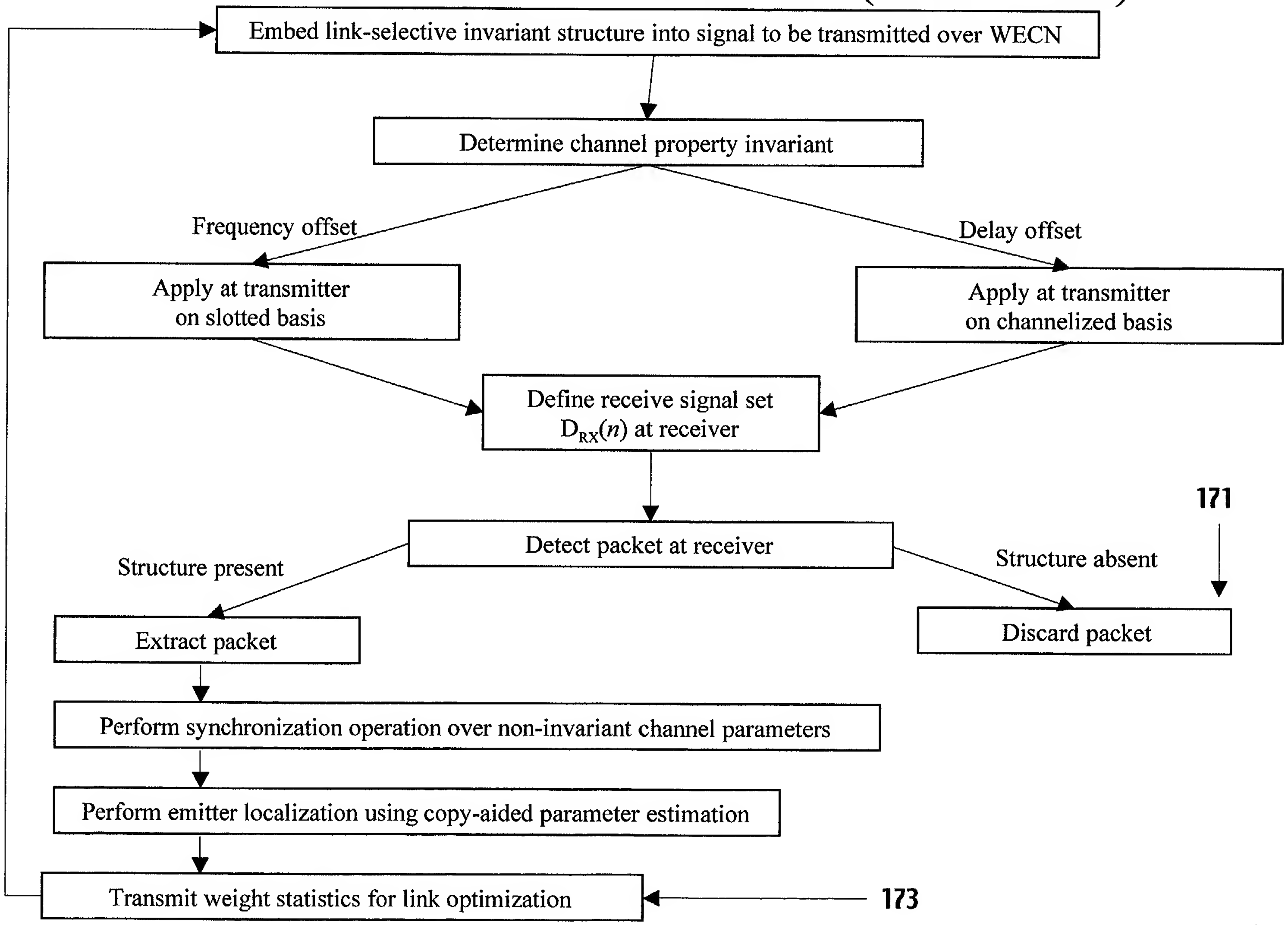


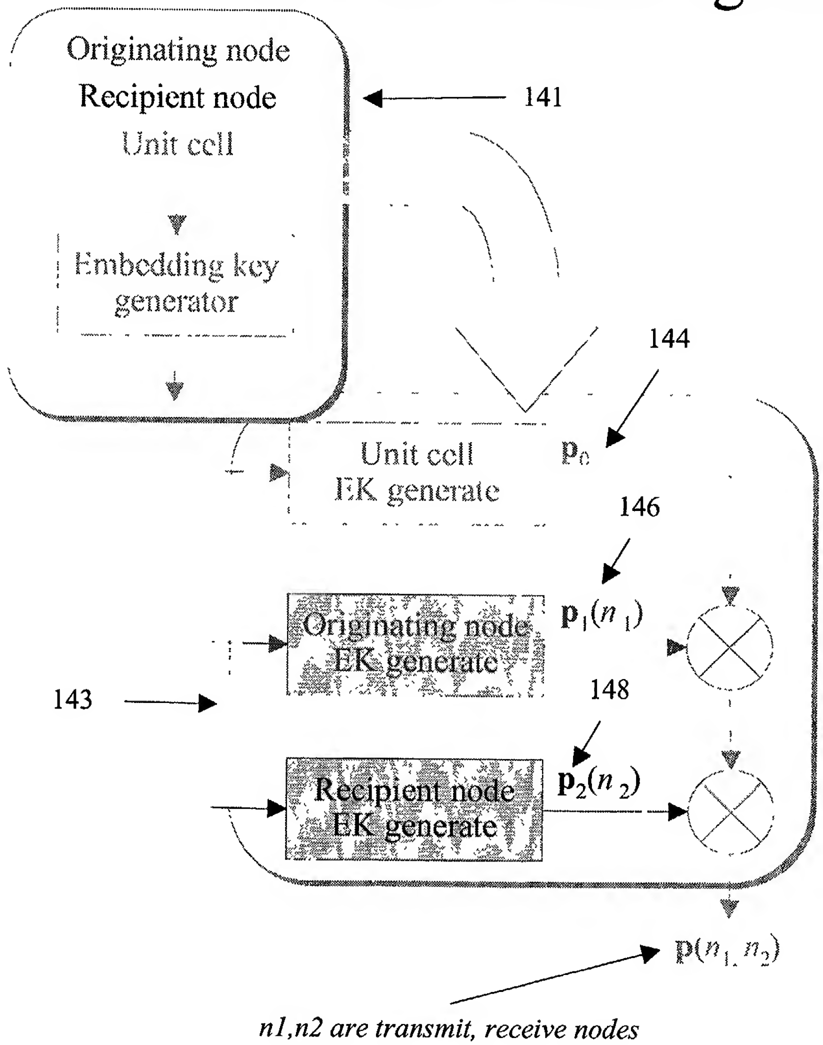
Figure 12

Embedded Invariance Flowchart (Link View)



Figure

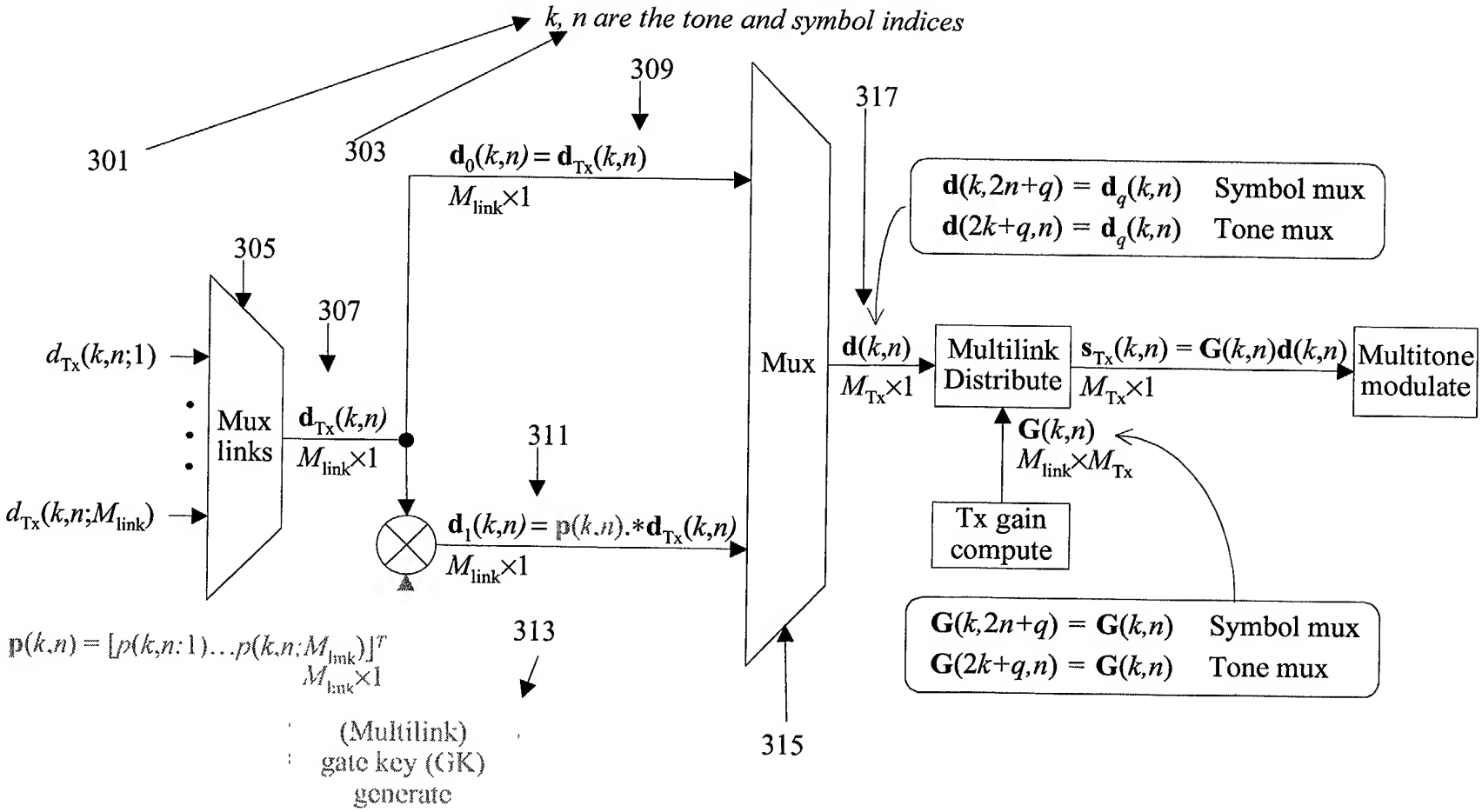
Multilink Embedding Key Generation Algorithm



$\mathbf{p}_0$		$[c_0(k)]_{k=0,\ldots,K-1}$
K		Number tones used by link
$c_0(k)$	=	Pseudorandom sequence, shared by all nodes in same subnet (can vary over tones and symbols)
$\mathbf{p}_1(n_1)$		$[p_1(k;n_1)]_{k=0,\ldots,K-1}$
$p_1(k;n_1)$	=	$\exp[-j\,2\pi k\, m(n_1)/L]$
$m(n_1)$		node <u>pseudodelay</u>, unique to (transmit) node n_1 in the subnet (varied over symbols to improve security)
$\mathbf{p}_2(n_2)$	=	$[c_2(k;n_2)]_{k=0,\ldots,K-1}$
$c_2(k;n_2)$	=	Pseudorandom sequence, unique to (receive) node n_2 in subnet (varied over symbols to improve security)
145		
$\mathbf{p}(n_1, n_2)$	=	$\mathbf{p}_0 .* \mathbf{p}_1(n_1) .* \mathbf{p}_2(n_2)$
		$[c_0(k) p_1(k;n_1) c_2(k;n_2)]_{k=0,\ldots,K-}$

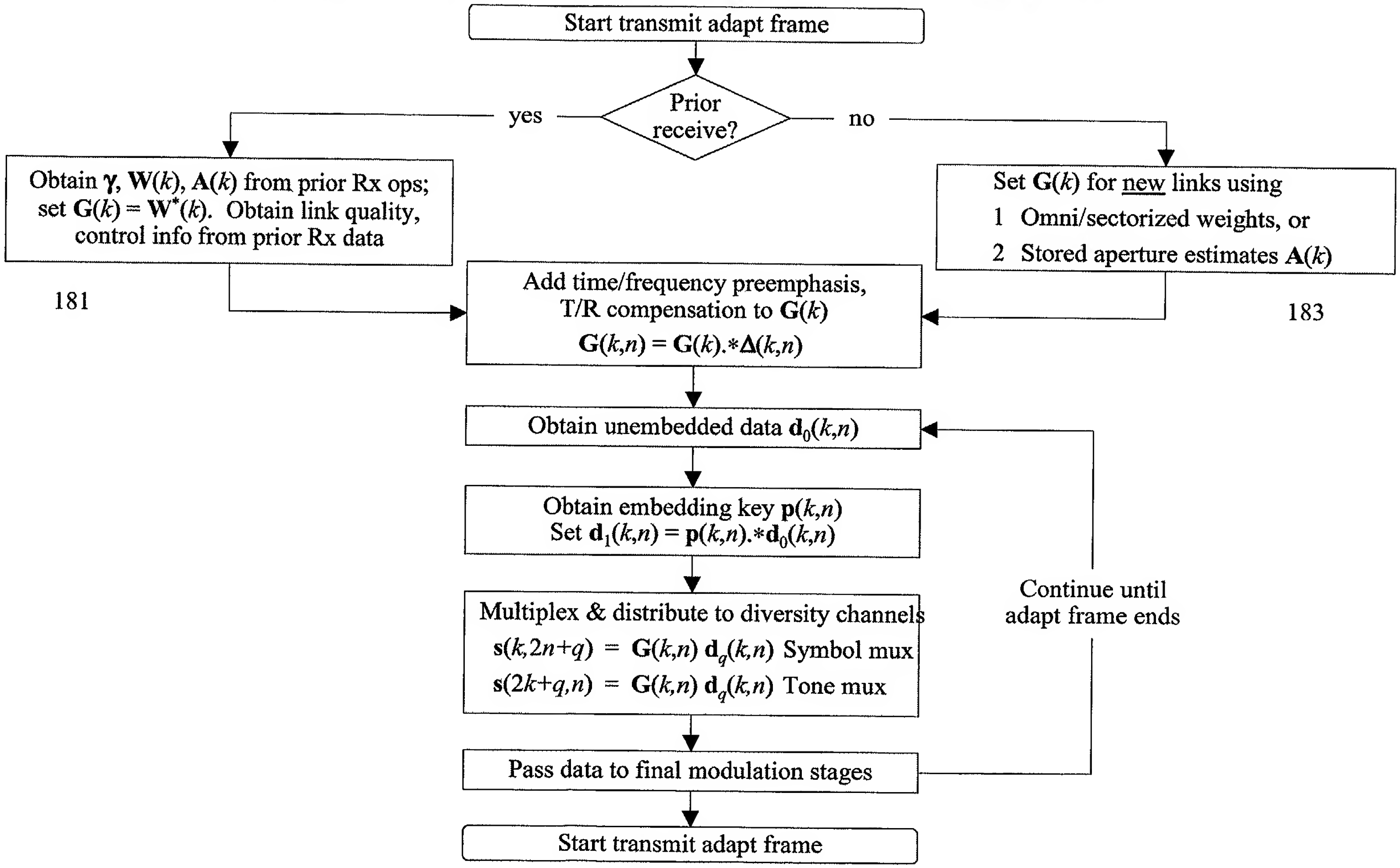
Figure

Multilink Transmit Embedding Hardware (Node n_1)



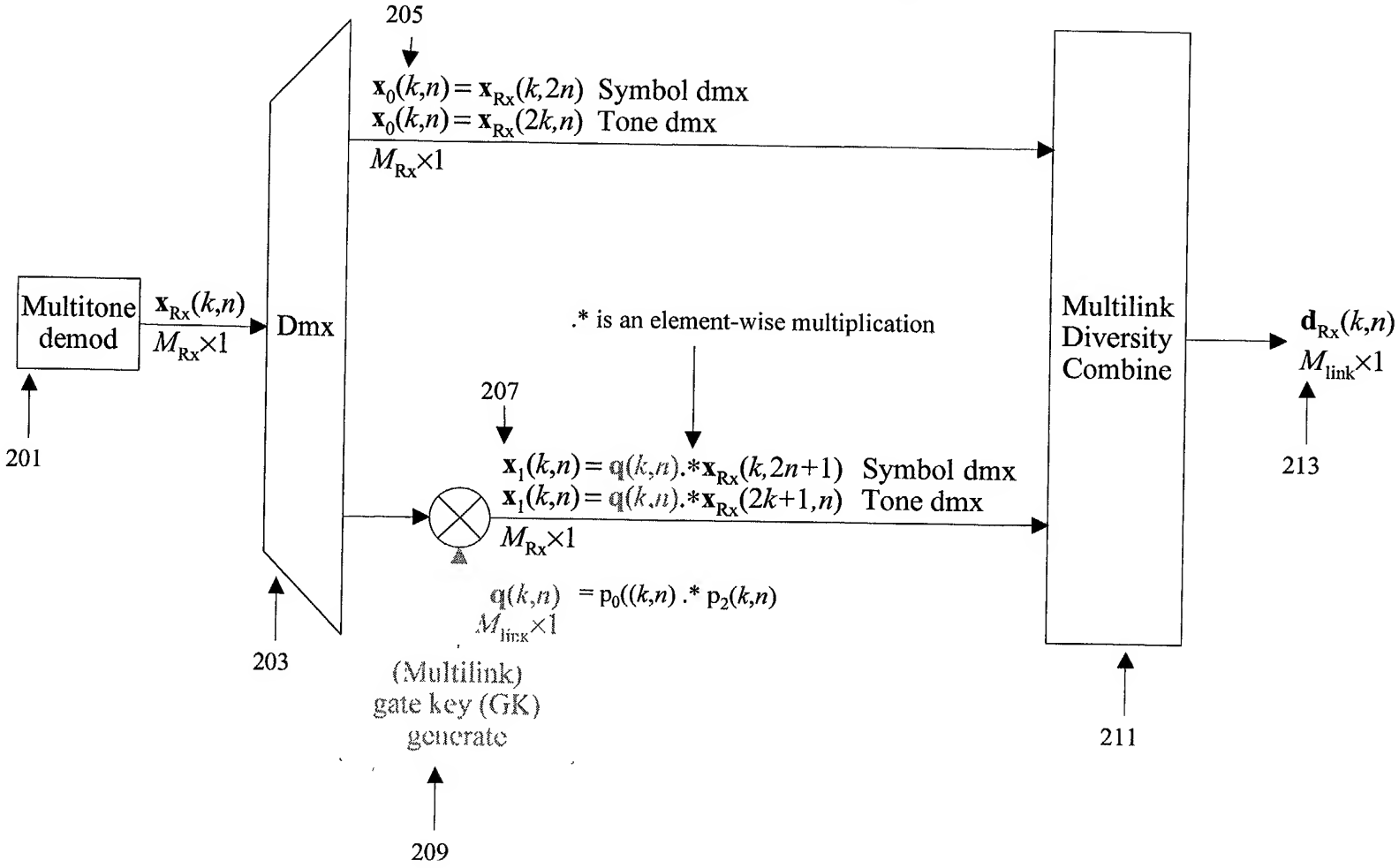
Figure

Multilink Embedding Flow Diagram



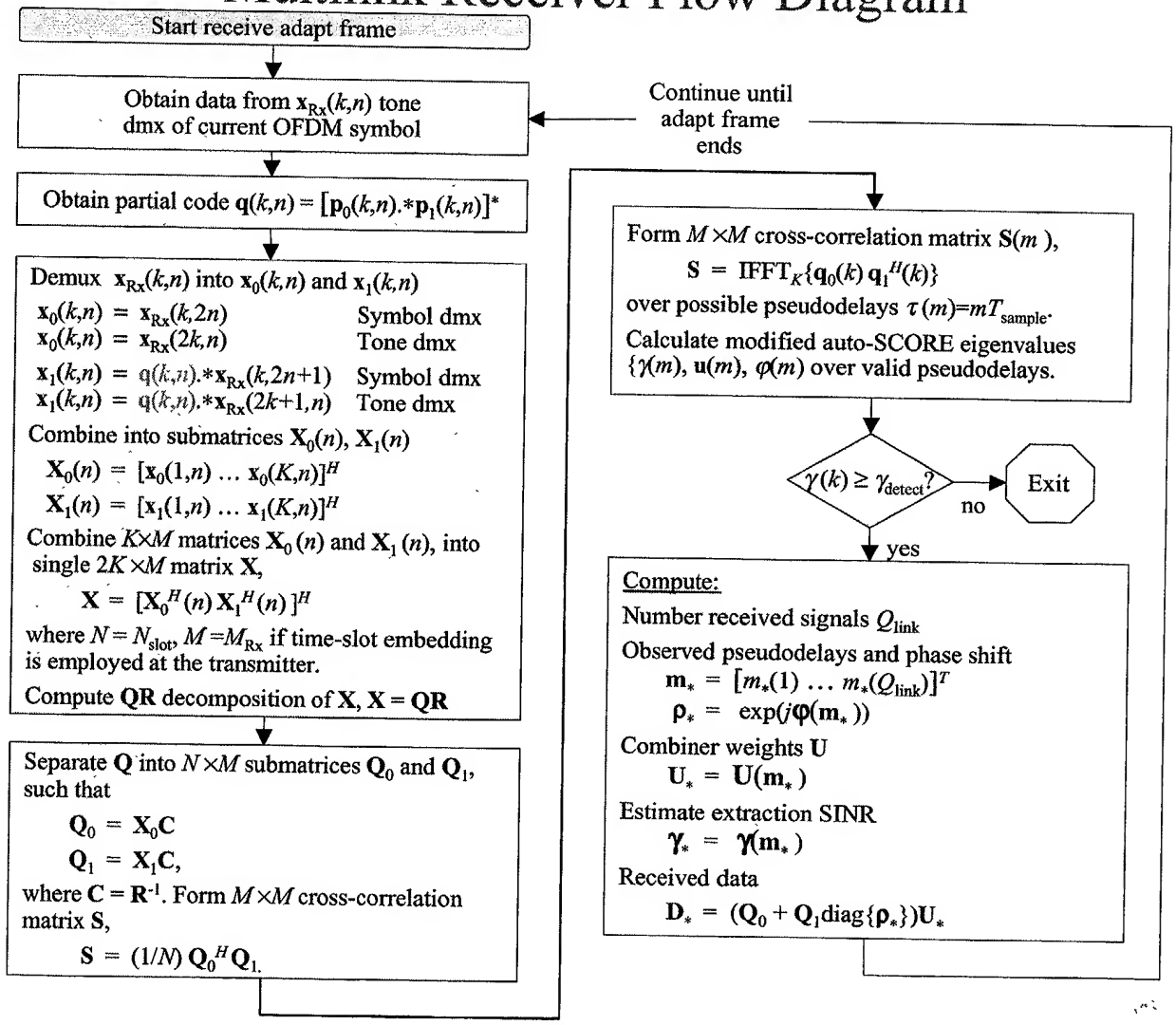
Figure

Multilink Receive Embedding Hardware



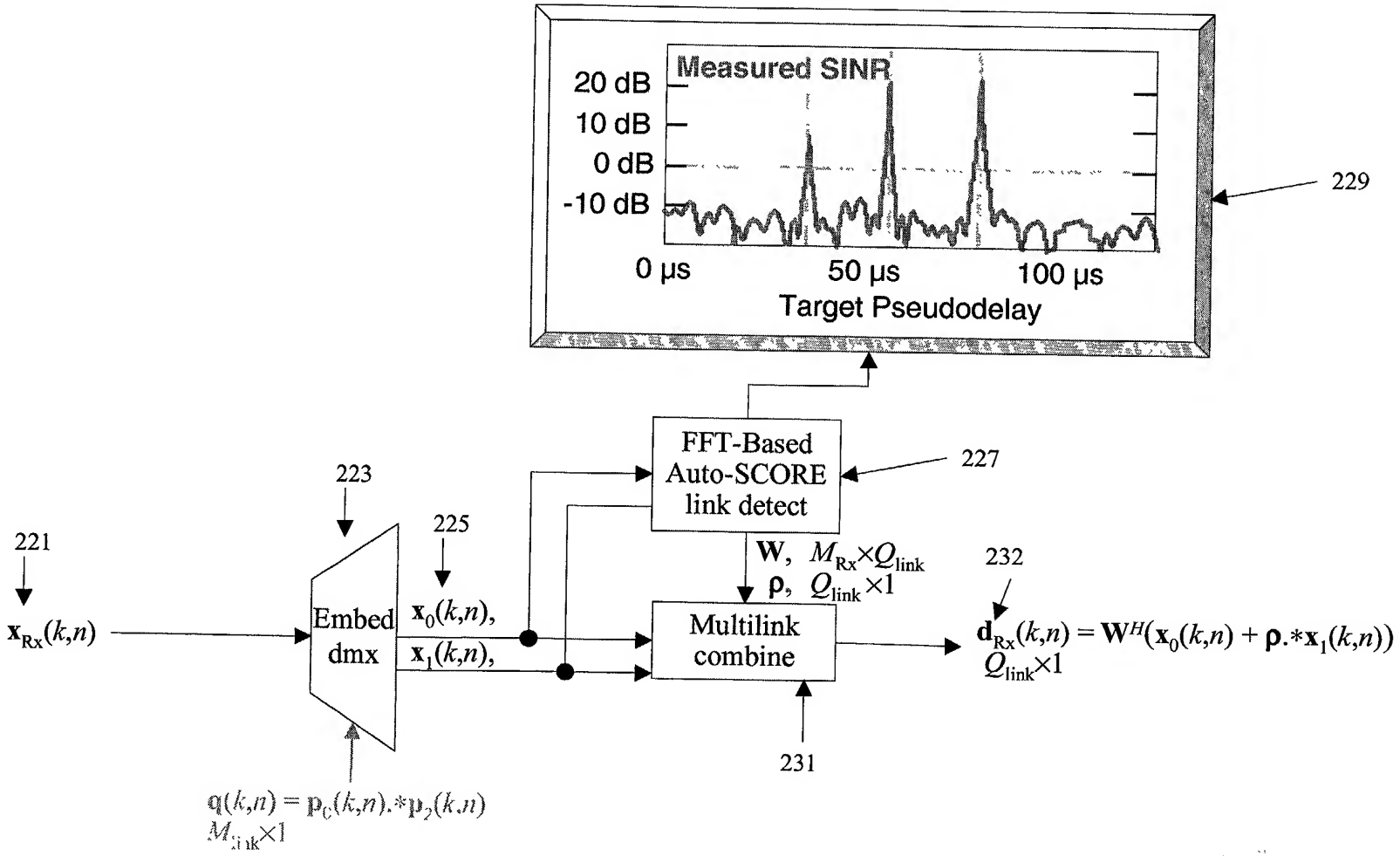
Figure

Multilink Receiver Flow Diagram



Figure

Link Detection, Separation Operation



Figure

Pseudodelay Plots and Antenna Patterns

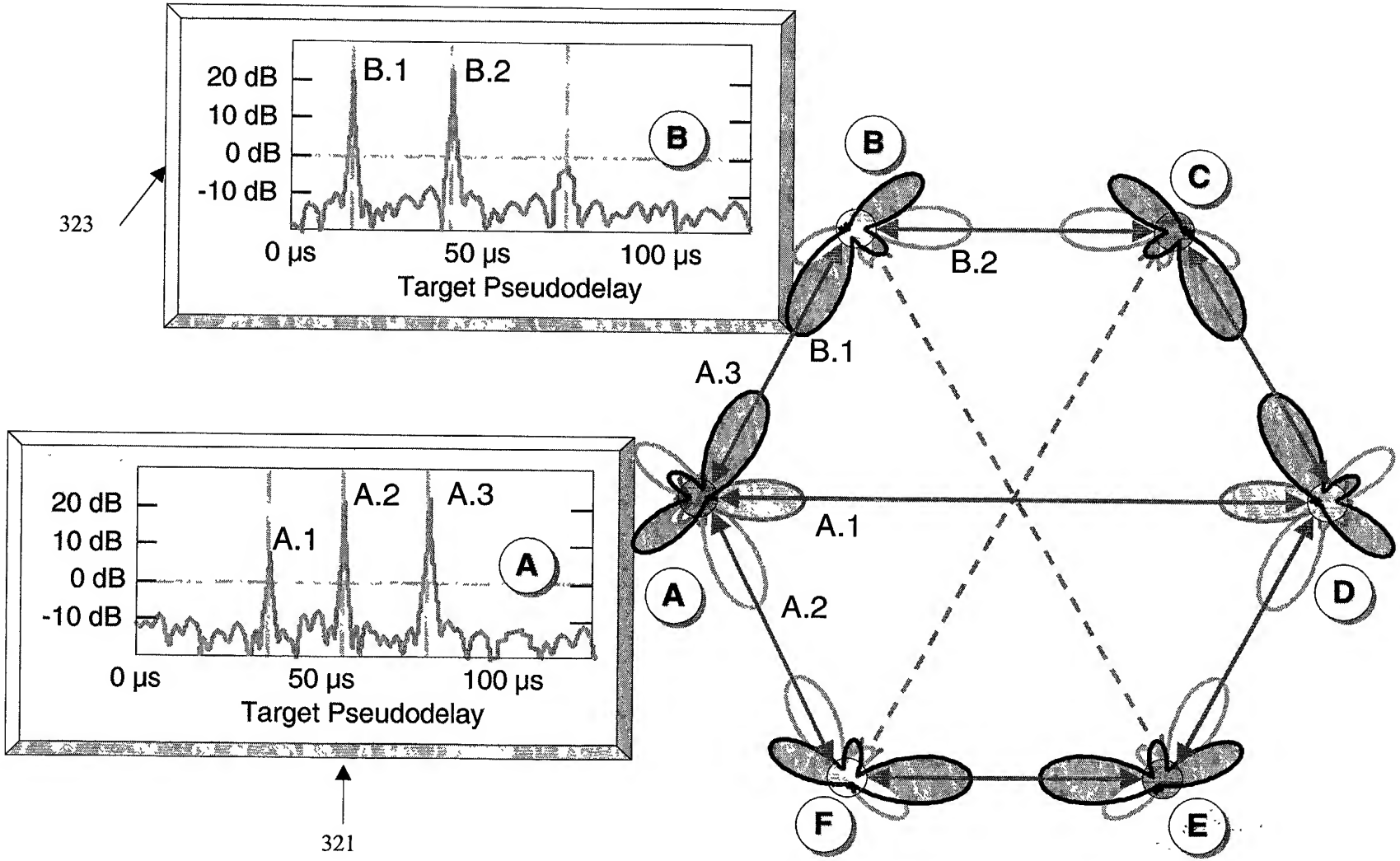


Figure 20